ENVIRONMENTAL PHYSIOLOGY

TEMPERATURE
AND
TEMPERATURE REGULATION

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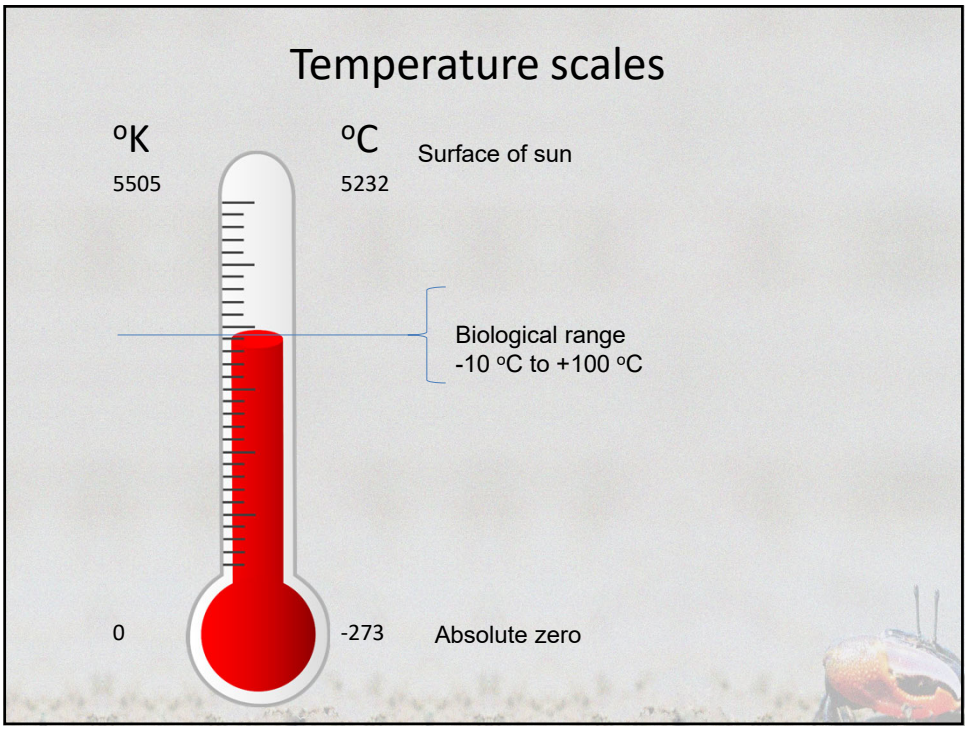
Temperature scales



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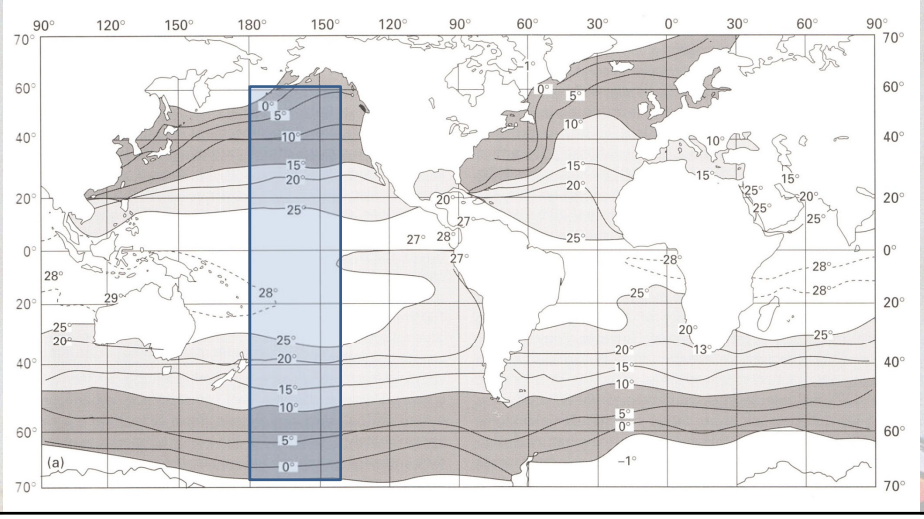
Temperature of sea water (where life evolved)

Surface Temperatures: 0 to 28 oC



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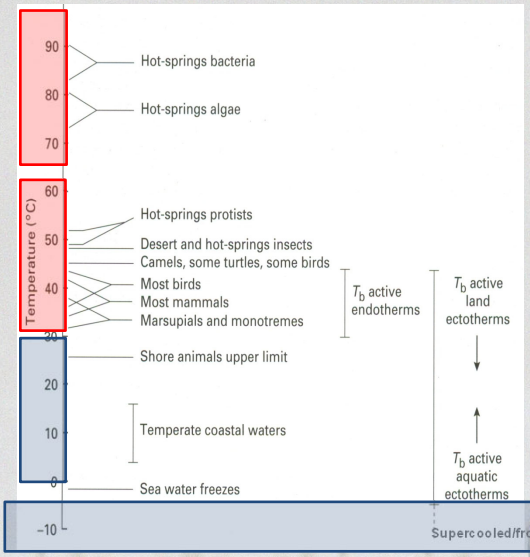
Thermal ranges for life

Hot Springs

Sea Water



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Reaction energetics

Free Energy$_{reactants}$ > Free Energy$_{products}$

Environmental thermal energy (temperature) provides the activation energy (ΔG*)

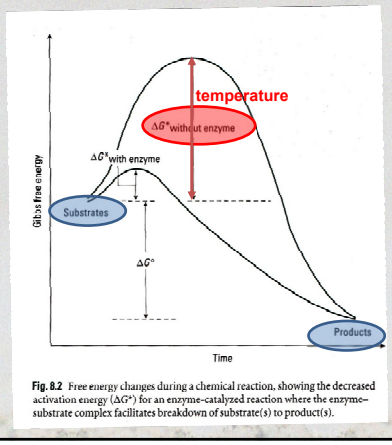

Fig. 8.2 Free energy changes during a chemical reaction, showing the decreased activation energy (ΔG*) for an enzyme-catalyzed reaction where the enzyme–substrate complex facilitates breakdown of substrate(s) to product(s).

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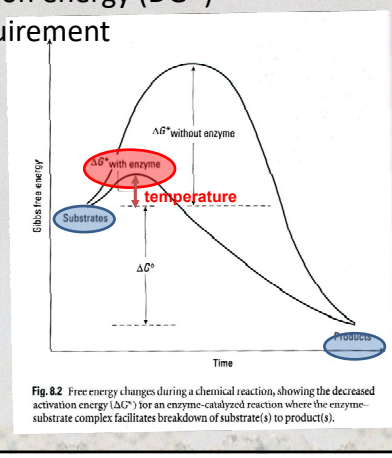
Reaction energetics

Free Energy$_{reactants}$ > Free Energy$_{products}$

Enzymes reduce the activation energy (DG*)
hence the temperature requirement



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Temperature effect for physiologists: Q_{10}

Q_{10} is the fractional increase in a reaction rate due to a 10 °C increase in temperature

$Q_{10} = k_2(T+10)/k_1(T)$

$Q_{10} = (k_2/k_1)^{10/(T_2-T_1)}$

$k_2 = k_1 Q_{10}^{((T_2 - T_1)/10)}$

Table 8.1 Q_{10} values for a variety of reactions involved in biological processes.

	Temperature (°C)	Q_{10}
Physical reactions		
Diffusion	20	1.03
Biochemical reactions		
Cytochrome reductase (possum)	>20	1.5
	<20	2.5
Pyruvate kinase V_{max} (rat)	>25	1.7
	<25	3.2
Hemoglobin coagulation	60	13.8
Physiological reactions		
Anemone oxygen consumption	5	2.0
	15	2.3
Crayfish heart rate	5	2.4
	15	1.6
	25	0.8
Crustacean gill movements	5	3.8
	15	1.7
Beetle oxygen consumption	10	2.4
	20	2.1
Insect thermal induction of diapause	20	1.4
	10	3.7
Torpid mammal oxygen consumption	20	4.1

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Enzyme adaptations to changes in temperature

Three time scales:

- Rapid (minutes to hours)
- Medium-term (days to weeks)
- Evolutionary time (many generations, thousands to millions of years)

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Rapid enzyme adaptations to temperature (minutes to hours)

Four mechanisms:

- Change enzyme concentration
  (e.g. phosphorylation, compartmentalization, allosteric modulation by activators/inhibitors)
- Change substrate concentration (by binding)
- Increase energy supply for a reaction (e.g. ATP)
- Change intracellular environment (e.g. K+, H+)

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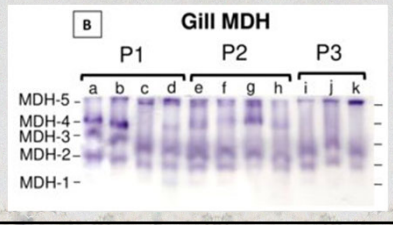
Medium-term enzyme adaptations to temperature (days to weeks to months)

- Protein synthesis/degradation to change enzyme concentration
- enzyme isozymes hence catalytic capacity (Km)

  isozymes are different forms of the same enzyme that vary in catalytic properties



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Acclimatisation/acclimation

Acclimatisation to seasonal temperature change

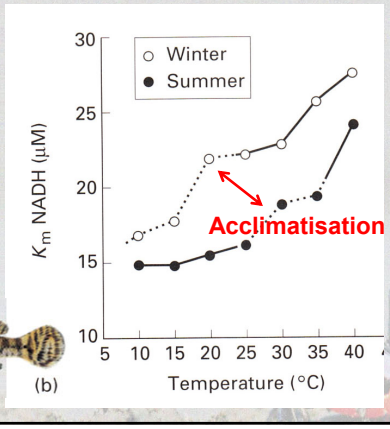
Acclimation is similar but in the laboratory.

Changes in

- Enzyme levels
- Enzyme properties

  catalytic function (Km, Kcat)
- cofactors/modulators

e.g. goby Gillichthys



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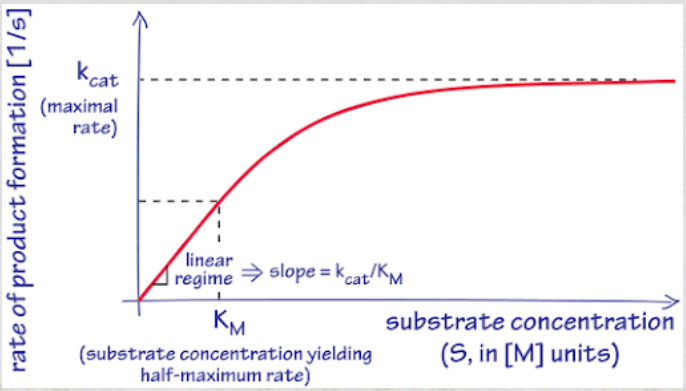
The effect of substrate concentration on K_m

Changes in enzyme isozyme synthesis:

enzyme affinity (Km)

catalytic function (Kcat)



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Evolutionary enzyme adaptations to temperature (adaptations)

Genotypic changes in enzyme concentrations

Genotypic changes in enzyme function e.g. Km modulation or thermal denaturation temperature of enzymes

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Enzyme affinity (K_m) modulation

Species **environment** adaptation

Optimal (lowest) K_m matches preferred T_b

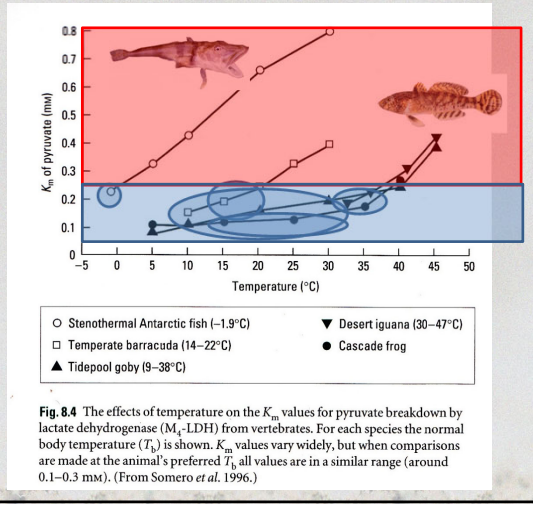

Fig. 8.4 The effects of temperature on the K_m values for pyruvate breakdown by lactate dehydrogenase (M_4-LDH) from vertebrates. For each species the normal body temperature (T_b) is shown. K_m values vary widely, but when comparisons are made at the animal's preferred T_b all values are in a similar range (around 0.1–0.3 mM). (From Somero *et al.* 1996.)

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LDH Kcat substrate turnover

Table 8.2 Substrate turnover rates (K_{cat}) for lactate dehydrogenase (LDH) from barracuda (see also Fig. 11.9), showing the similar (conserved) values for different species when measured at normal operating temperatures.

Species (distribution)	Normal mean temperature of habitat (T_m) (°C)	K_{cat} at 25°C (s^{-1})	K_{cat} at T_m (s^{-1})
Sphyraena argentea (northern)	18	893 **high**	667 **OK**
Sphyraena lucasana (intermediate)	23	730 **high**	682 **OK**
Sphyraena ensis (southern)	26	658 **OK**	700 **OK**

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Physiological effects of temperature

- Rate-enhancing (Q_{10}) effects at low T_a
- Destructive (denaturing) effects at high T_a
- Optimum temperature

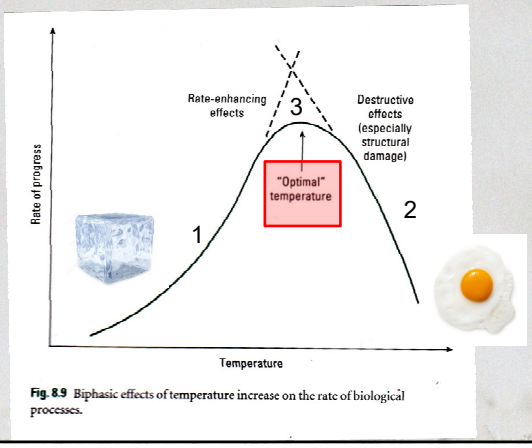

Fig. 8.9 Biphasic effects of temperature increase on the rate of biological processes.

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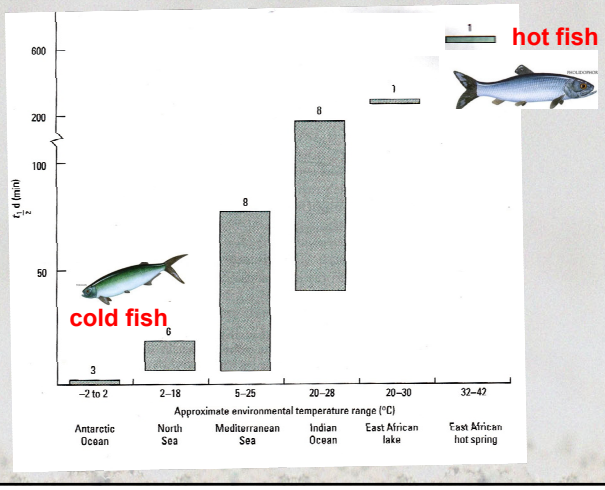
Thermal denaturation

Myofibrillar ATPase denaturation temperature varies environmentally in fishes

Time for 50% denaturation **at 37 °C**



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Upper critical body temperatures

UCT or CT_{max}

Table 8.6 Upper critical temperature (UCT) for a variety of animals from different habitats.

Group	Example (habitat)	UCT (°C)
Prokaryotes	Bacteria (aquatic)	70–75
	Bacteria (thermophilic)	90–91
	Cyanobacteria	75
Molluscs	*Modiolus* (SW bivalve)	38
	Nassa (SW gastropod)	42
	Clavarizona (SW gastropod)	43
Annelids	*Lumbricus* (land earthworm)	29
Echinoderms	*Asterias* (SW starfish)	32
	Ophioderma (SW brittlestar)	37
Crustaceans	*Palaeomonetes* (SW/littoral prawn)	34
	Porcellio (SW crab)	39–41
	Uca (littoral/land crab)	39–45
	Armadillidium (land woodlouse)	41–42
Insects	*Lepisma* (land springtail)	36
	Thermobia (land firebrat)	40+
	Sphingonotus (land moth)	41
	Bembex (land sandwasp)	42
	Onymacris (desert beetle)	49–51
	Dasymutilla (land sandwasp)	52
	Ocymyrmex (desert ant)	51.5
	Melophorus (desert ant)	54
Arachnids	*Buthotus* (land scorpion)	45
	Leiurus (land scorpion)	47
Vertebrates		
Fish	*Pagothenia* (polar SW)	6–10
	Fundulus (cold SW)	35
Amphibians	Salamanders (FW/land)	29–35
	Anurans (FW/land)	36–41
Reptiles	Alligators (land/FW)	38
	Turtles (SW/land)	41
	Lizards (land/desert)	40–47
	Snakes (land)	40–42
Birds	Passerines	46–47
	Nonpasserines	44–46
Mammals	Monotremes	37
	Marsupials	40–41
	Placentals	42–44

FW, fresh water; SW, sea water.

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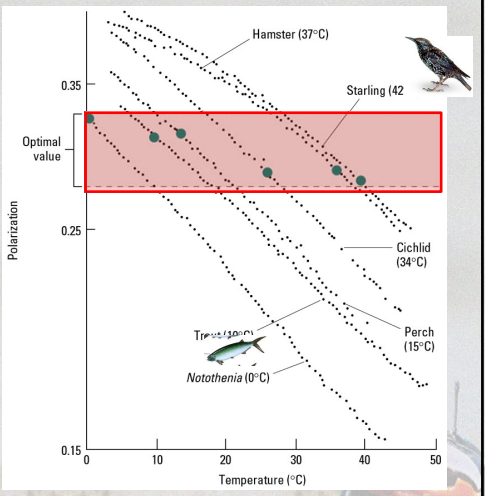
Temperature effects on membranes

HOMEO-VISCOUS ADAPTATION
maintains appropriate membrane fluidity (polarization) at different temperatures



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Temperature effects on membranes

HOMEO-VISCOUS ADAPTATION

Phospholipid type affects fluidity

Double-bonds disrupt structure and increase fluidity, and ratio changes with temperature

Table 8.3 The ratio of saturated to unsaturated fatty acid residues in three phospholipids from cell membranes in brain tissues of various vertebrates acclimated to different temperatures.

Species	Body temperature (°C)	Phospholipid: Choline	Ethanolamine	Serine inositol
Arctic sculpin	0	0.59	0.95	0.81
Goldfish	5	0.66	0.34	0.46
	25	0.82	0.51	0.63
Desert pupfish	34	0.99	0.57	0.62
Rat	37	1.22	0.65	0.66

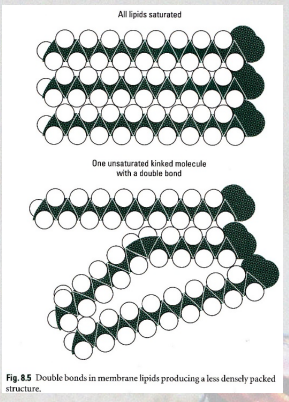

Fig. 8.5 Double bonds in membrane lipids producing a less densely packed structure.

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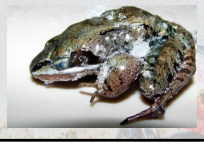
Freezing temperature responses

Freeze-intolerant (or freeze-avoiding)

Supercool to below freezing but die if ice forms
e.g. ice-fish, Arctic squirrel (-5°C)

Lower their freezing point e.g. ice-fish

Freeze-tolerant
survive freezing of at least some extracellular body water e.g. frogs,
intertidal mussels



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Freeze-intolerant animals

- Supercooling avoids freezing below the nominal freezing temperature (but melting temperature has the expected colligative value)
- Solute effects lower freezing/melting point

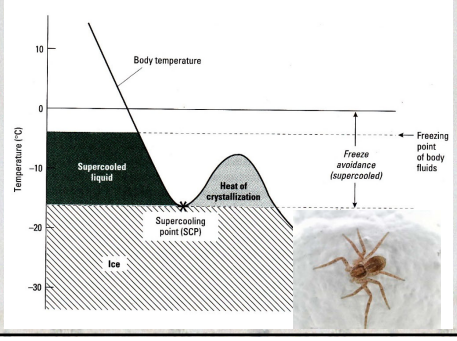

Table 8.4 Freezing points and melting points of body and blood fluids from some cold-hardy animals showing thermal hysteresis.

Genus	Freezing point (blood) (°C)	Melting point (blood) (°C)	Supercooling temperature (°C)
Spiders			
Philodromus	−5.2	−2.7	−26.2
Clubiona	−4.8	−2.9	−15.4
Insects			
Meracantha	−5.0	−1.3	−10.3
Dendroides	−7.0	−3.4	−9.5
Fish			
Gadus (cod)	−1.1	−0.7	
Rhigophalia (eel pout)	−2.0	−0.9	
Myxocephalus (sculpin)	−2.0	−1.1	
Eleginus	−2.2	−1.2	
Pagothenia	−2.7	−1.1	

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Cryo-protectants

- COLLIGATIVE effect: antifreeze effect is proportional to concentration e.g. glycerol
  4 colligative properties of solutions – effect proportional to concentration
  - freezing point
  - boiling point
  - water vapour pressure
  - osmotic pressure
- You need a lot of solute for a small effect.
- It affects the freezing and thawing temperatures the same.

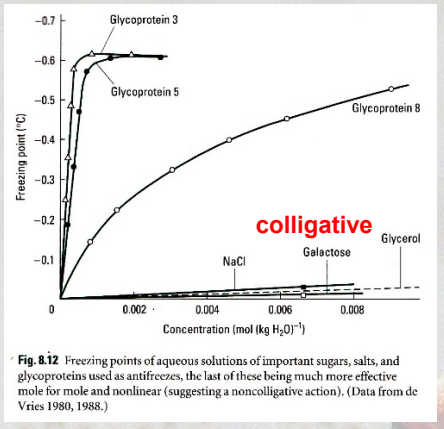
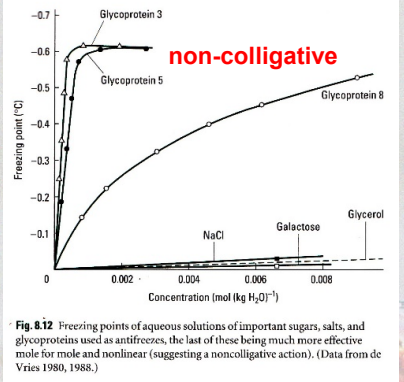


Fig. 8.12 Freezing points of aqueous solutions of important sugars, salts, and glycoproteins used as antifreezes, the last of these being much more effective mole for mole and nonlinear (suggesting a noncolligative action). (Data from de Vries 1980, 1988.)

Cryo-protectants

- NON-COLLIGATIVE effect: some antifreezes have a greater freezing point depression than expected from their molar concentration e.g. ice-fish antifreeze proteins
- You don't need much solute for a big effect.
- It decreases the freezing point more than the thawing point.



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